

## CLAIMS

I claim:

- 1           1.       A method comprising:
  - 2           pruning local graphs representing local problems, the local problems
  - 3           corresponding to separately compilable components in a software program, each
  - 4           of the local graphs having edges and vertices, each edge having a transfer
  - 5           function, each vertex having a value, values of each of the local graph forming a
  - 6           lattice under a partial ordering.
- 1           2.       The method of claim 1 wherein pruning the local graphs
  - 2           comprising:
    - 3           associating a use attribute to each one of the vertices in each of the local
    - 4           graphs, the use attribute being asserted for each vertex reachable from a named
    - 5           vertex;
    - 6           associating an affect attribute to each one of the vertices in each of the
    - 7           local graphs, the affect attribute is asserted for a vertex if a named vertex is
    - 8           reachable from the former vertex; and
    - 9           pre-solving a subgraph of each of the local graphs, the subgraph including
    - 10          subgraph edges, each of the subgraph edges connecting a tail vertex to a head
    - 11          vertex, the tail vertex having a negated use attribute.

1           3.     The method of claim 2 wherein pruning the local graphs further  
2 comprising:  
3           shrinking the local graphs.

1           4.     The method of claim 3 further comprising solving a global problem  
2 to optimize a recompilation of the separately compilation components by an inter-  
3 procedural analysis (IPA) solver, the global problem being represented by a global  
4 graph formed from the pruned local graphs.

5           5.     The method of claim 4 wherein pruning the local graphs further  
6 comprising:  
7           determining final edges and vertex values of the local graphs to be sent to  
8 IPA solver; and  
9           sending the final edges and vertex values to the IPA solver, the final edges  
10 and vertex values forming the pruned local graphs.

1           6.     The method of claim 2 wherein associating the use attribute  
2 comprises:  
3           negating use attributes for all vertices in the local graph; and  
4           invoking a mark use operation on u for each named vertex u in the local  
5 graph.

1           7.       The method of claim 6 wherein invoking the mark use operation on  
2    u comprises:

3           asserting the use attribute associated with u if the use attribute is negated;

4    and

5           recursively invoking the mark use operation on v for each edge connecting  
6    the named vertex u to a vertex v.

1           8.       The method of claim 2 wherein associating the affect attribute  
2    comprises:

3           negating use attributes for all vertices in the local graph;

4           invoking a mark affect operation on y for each named vertex y in the local  
5    graph.

1           9.       The method of claim 8 wherein invoking the mark affect operation  
2    on y comprises:

3           asserting the use attribute associated with y if the use attribute is negated;

4    and

5           recursively invoking the mark affect operation on x for each edge  
6    connecting the vertex x to a named vertex y.

1           10.     The method of claim 2 wherein pre-solving the subgraph  
2     comprises:  
3           finding a greatest fix-point solution to the subgraph.

1           11.     The method of claim 3 wherein shrinking comprises:  
2           removing an incoming edge having a head value of a lattice-bottom.

1           12.     The method of claim 3 wherein shrinking further comprises:  
2           transforming a subgraph having first and second edges, the first and  
3     second edges having first and second functions, the first edge connecting a first  
4     vertex to an anonymous vertex having a value  $v$ , the second edge connecting the  
5     anonymous vertex to a second vertex having a value  $w$ .

1           13.     The method of claim 12 wherein transforming comprises:  
2           removing the anonymous vertex;  
3           removing first and second edges;  
4           adding a third edge having a third function and connecting the first and  
5     second vertices, the third function being combined by the first and second  
6     functions; and

7 changing value of the second vertex to a lattice meet of the second  
8 function of the value v and the value w.

1 14. The method of claim 5 wherein determining the final edges and  
2 vertex values comprises:  
3 determining each of the final edges as edge having asserted use and affect  
4 attributes for tail and head vertices, respectively; and  
5 eliding each of the vertex values having a top value.

1 15. A computer program product comprising:  
2 a machine useable medium having computer program code embedded  
3 therein, the computer program product having:  
4 computer readable program code to prune local graphs representing local  
5 problems, the local problems corresponding to separately compilable components  
6 in a software program, each of the local graphs having edges and vertices, each  
7 edge having a transfer function, each vertex having a value, values of each of the  
8 local graph forming a lattice under a partial ordering.

1 16. The computer program product of claim 15 wherein the computer  
2 readable program code to prune the local graphs comprising:

3 computer readable program code to associate a use attribute to each one of  
4 the vertices in each of the local graphs, the use attribute being asserted if there is  
5 an edge connecting a named vertex to the each one of the vertices;

6 computer readable program code to associate an affect attribute to each  
7 one of the vertices in each of the local graphs, the affect attribute is asserted if  
8 there is an edge connecting the each one of the vertices to a named vertex; and

9 computer readable program code to pre-solve a subgraph of each of the  
10 local graphs, the subgraph including subgraph edges, each of the subgraph edges  
11 connecting a tail vertex to a head vertex, the tail vertex having a negated use  
12 attribute.

1 17. The computer program product of claim 16 wherein the computer  
2 readable program code to prune the local graphs further comprising:

3 computer readable program code to shrink the local graphs.

1 18. The computer program product of claim 15 further comprising:

2 computer readable program code to solve a global problem to optimize a  
3 recompilation of the separately compilation components by an inter-procedural  
4 analysis (IPA) solver, the global problem being represented by a global graph  
5 formed from the pruned local graphs.

1 19. The computer program product of claim 18 wherein the computer  
2 readable program code to prune the local graphs further comprising:

3 computer readable program code to determine final edges and vertex  
 4 values of the local graphs to be sent to IPA solver; and  
 5 computer readable program code to send the final edges and vertex values  
 6 to the IPA solver, the final edges and vertex values forming the pruned local  
 7 graphs.

1 20. The computer program product of claim 16 wherein the computer  
 2 readable program code to associate the use attribute comprises:  
 3 computer readable program code to negate use attributes for all vertices in  
 4 the local graph;  
 5 computer readable program code to invoke a mark use operation on u for  
 6 each named vertex u in the local graph.

1 21. The computer program product of claim 19 wherein the computer  
 2 readable program code to invoke the mark use operation on u comprises:  
 3 computer readable program code to assert the use attribute associated with  
 4 u if the use attribute is negated; and  
 5 computer readable program code to recursively invoke the mark use  
 6 operation on v for each edge connecting the named vertex u to a vertex v.

1 22. The computer program product of claim 16 wherein the computer  
 2 readable program code to associate the affect attribute comprises:

3 computer readable program code to negate use attributes for all vertices in  
4 the local graph; and

5 computer readable program code to invoke a mark affect operation on y  
6 for each named vertex y in the local graph.

1 23. The computer program product of claim 22 wherein the computer  
2 readable program code to invoke the mark affect operation on y comprises:

3 computer readable program code to assert the use attribute associated with  
4 y if the use attribute is negated; and

5 computer readable program code to recursively invoke the mark affect  
6 operation on x for each edge connecting the vertex x to a named vertex y.

1 24. The computer program product of claim 16 wherein the computer  
2 readable program code to pre-solve the subgraph comprises:

3 computer readable program code to find a greatest fix-point solution to the  
4 subgraph.

1 25. The computer program product of claim 17 wherein the computer  
2 readable program code to shrink comprises:

3 computer readable program code to remove an incoming edge having a  
4 head value of a lattice-bottom.



1           26.     The computer program product of claim 17 wherein the computer  
2     readable program code to shrink further comprises:

3           computer readable program code to transform a subgraph having first and  
4     second edges, the first and second edges having first and second functions, the  
5     first edge connecting a first vertex to an anonymous vertex having a value  $v$ , the  
6     second edge connecting the anonymous vertex to a second vertex having a value  
7      $w$ .

1           27.     The computer program product of claim 26 wherein the computer  
2     readable program code to transform comprises:

3           computer readable program code to remove the anonymous vertex;

4           computer readable program code to remove first and second edges;

5           computer readable program code to add a third edge having a third  
6     function and connecting the first and second vertices, the third function being  
7     combined by the first and second functions; and

8           computer readable program code to change value of the second vertex to a  
9     lattice meet of the second function of the value  $v$  and the value  $w$ .

1           28.     The computer program product of claim 19 wherein the computer  
2     readable program code to determine the final edges and vertex values comprises:

3 computer readable program code to determine each of the final edges as  
4 edge having asserted use and affect attributes for tail and head vertices,  
5 respectively; and

6 computer readable program code to elide each of the vertex values having  
7 a top value.

1 29. A system comprising:

2 a processor; and

3 a memory coupled to the processor to store instruction code, the  
4 instruction code, when executed by the processor, causing the processor to:

5 prune local graphs representing local problems, the local problems  
6 corresponding to separately compilable components in a software  
7 program, each of the local graphs having edges and vertices, each edge  
8 having a transfer function, each vertex having a value, values of each of  
9 the local graph forming a lattice under a partial ordering.

1 30. The system of claim 29 wherein the instruction code causing the  
2 processor to prune the local graphs causes the processor to:

3 associate a use attribute to each one of the vertices in each of the local  
4 graphs, the use attribute being asserted if there is an edge connecting a named  
5 vertex to the each one of the vertices;

6           associate an affect attribute to each one of the vertices in each of the local  
7   graphs, the affect attribute is asserted if there is an edge connecting the each one  
8   of the vertices to a named vertex; and

9           pre-solve a subgraph of each of the local graphs, the subgraph including  
10   subgraph edges, each of the subgraph edges connecting a tail vertex to a head  
11   vertex, the tail vertex having a negated use attribute.

1           31.    The system of claim 30 wherein the instruction code causing the  
2   processor to prune the local graphs further causes the processor to:

3           shrink the local graphs.

1           32.    The system of claim 31 wherein the instruction code further  
2   causing the processor to:

3           solve a global problem to optimize a recompilation of the separately  
4   compilation components by an inter-procedural analysis (IPA) solver, the global  
5   problem being represented by a global graph formed from the pruned local  
6   graphs.

7           33.    The system of claim 32 wherein the instruction code causing the  
8   processor to prune the local graphs further causes the processor to:

9           determine final edges and vertex values of the local graphs to be sent to  
10   IPA solver; and

11            send the final edges and vertex values to the IPA solver, the final edges  
12            and vertex values forming the pruned local graphs.

1            34.    The system of claim 30 wherein the instruction code causing the  
2            processor to pre-solve the subgraph causes the processor to:

3            find a greatest fix-point solution to the subgraph.

1            35.    The system of claim 31 wherein the instruction code causing the  
2            processor to shrink causes the processor to:

3            remove an incoming edge having a head value of a lattice-bottom.

1            36.    The system of claim 35 wherein the instruction code causing the  
2            processor to shrink further causes the processor to:

3            transform a subgraph having first and second edges, the first and second  
4            edges having first and second functions, the first edge connecting a first vertex to  
5            an anonymous vertex having a value v, the second edge connecting the  
6            anonymous vertex to a second vertex having a value w.

1            37.    The system of claim 36 wherein the instruction code causing the  
2            processor to transform causing the processor to:

3            remove the anonymous vertex;

4            remove first and second edges;

5           add a third edge having a third function and connecting the first and  
6   second vertices, the third function being combined by the first and second  
7   functions; and  
  
8           change value of the second vertex to a lattice meet of the second function  
9   of the value v and the value w.

1           38.    The system of claim 33 wherein the instruction code causing the  
2   processor to determine the final edges and vertex values causes the processor to:  
  
3           determine each of the final edges as edge having asserted use and affect  
4   attributes for tail and head vertices, respectively; and  
  
5           elide each of the vertex values having a top value.